

AVALON BAY WATER QUALITY IMPROVEMENT PROJECT, CATALINA ISLAND, CALIFORNIA

A final report for the

Clean Beaches Initiative Grant

Agreement # 07-582-550-2

**Submitted to the City of Avalon and the State
Water Resources Control Board on 3/10/11 by**

**Stanley B. Grant, Rachel Litton, Lin Ho, Morgan Bailey, Jordan
Monroe**

**Henry Samueli School of Engineering
University of California, Irvine**

**Stefan Wuertz
School of Engineering
University of California, Davis**

**Lanbo Liu
School of Engineering
University of Connecticut**

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Principal Investigator and City of Avalon Contact Information:

Stanley B. Grant

Professor
Dept. Chemical Engineering and Materials Science
Dept. Civil and Environmental Engineering
Henry Samueli School of Engineering
University of California
Irvine, California 92697
(949) 824-8277
sbgrant@uci.edu

Stefan Wuertz

Professor
Department of Civil and Environmental Engineering
3157 Engineering III, 1 Shields Avenue
University of California Davis
Davis, California 95616
(530) 754-6407
swuertz@ucdavis.edu

Lanbo Liu

Associate Professor
Department of Civil and Environmental Engineering
University of Connecticut
Storrs, CT 06269-2037
(860) 486-1388
lanbo.liu@uconn.edu

Charlie Wagner

Chief Administrative Officer
City of Avalon
P.O. Box 707
Avalon, California 90704
(310) 510-0220 x116
charlie@cityofavalon.com

Summary

Background and Problem statement

The City of Avalon, located on Catalina Island, is a recreational destination for boaters, fisherman, divers, beach goers, and other ocean oriented visitors. In 1999 the County of Los Angeles began testing Avalon Bay for fecal indicator bacteria in accordance with AB 411. The test results frequently exceeded California single-sample standards for fecal indicator bacteria in coastal bathing waters, and as a result beaches in Avalon are frequently posted as unfit for swimming.

In response, a series of studies and mitigations efforts were undertaken:

- a) In 2000, Ms. Alison Davis in Jed Fuhrman's laboratory at USC was hired to conduct a microbial source tracking study, to determine if there was evidence of human fecal pollution in Avalon Bay. This study, which was very small in scope, found no evidence of human viruses in Avalon Bay. Based on the results of this very limited study, the City concluded that the fecal indicator bacteria problem in Avalon Bay was due to fecal material produced by birds, in particular pigeons. Accordingly, the City focused on controlling bird populations in and around the City
- b) In 2001, the City received a \$500,000 grant from the State of California's Clean Beaches Initiative to further investigate the water quality problem in Avalon Bay, and pursue mitigation measures. This grant had three goals: 1) to determine the sources of fecal indicator bacteria in the Bay, 2) to conduct further microbial source tracking studies, and 3) to characterize circulation in Avalon Bay. These studies, which were carried out by Professors Stanley Grant (UCI), Burt Jones (USC), and Jed Fuhrman (USC) between September and November 2001, concluded that:
 - i. Fecal indicator bacteria in Avalon Bay appear to originate from several land-side sources, including bird and animal fecal droppings, broken plumbing under wharf structures, run-off from street wash down activities, and contaminated shallow groundwater.
 - ii. Within Avalon Bay, fecal indicator bacteria concentrations are highest in ankle depth water along the shoreline. Fecal indicator bacteria concentrations in the water and sediment are generally below detectable levels a very short distance (<10 m) bayward of the shoreline.
 - iii. Microbial indicators of human fecal pollution (including the human-specific bacteria *Bacteroides/Provetella* and human enterovirus) were detected at several locations in Avalon Bay and in groundwater sampling pits, suggesting that human sewage may contribute to water quality impairment of Avalon Bay.
 - iv. The rates of advection and turbulent diffusion within Avalon Bay (*ca.* 1 to 6 cm/s and 1 m²/s, respectively) is sufficient to disperse contaminants introduced to the Bay within an hour or so, provided that the source of contamination is not continuous.

FINAL REPORT

- v. A significant fraction of the water in Avalon Bay is exchanged with the ocean over a single tide cycle.
- vi. The region of the Bay impacted by the storm drain (near the beach site called "Channel") does not appear to have a circulation problem. Within one hour, pollutants released into this area of the Bay are transported 80 to 100 m into the Bay and diluted by a factor of 100 or more.

Based on these results, the City implemented the following mitigation measures:

- i) Sewer mains and manholes in the first three blocks from the waterfront were slip-lined and sealed; this effort was completed in May, 2002.
- ii) Bird control measures were intensified; this ongoing effort was initiated in 2001.
- iii) Plumbing under the wharfs was repaired and a regular twice per year inspection program initiated.
- iv) Street wash down procedures were modified to prevent run-off.
- v) Sewer laterals in the first three blocks from the waterfront were repaired and sealed; this effort was initiated in May 2005 and completed in November 2005.

Current Project Purpose, Scope, Goals, and Activities

The City was also awarded a follow-up grant from the Clean Beaches Initiative (Agreement No. 07-582-550) to support the following activities:

Task B.1.: Characterize the extent of the sewage-contaminated shallow groundwater

Task B.2.: Conduct bench-scale pilot remediation study on sewage contaminated shallow groundwater.

Task B.3.: Identify the sources of fecal indicator bacteria in ankle-depth waters.

Task B.4.: Carry out capital improvement of the sewer infrastructure in Avalon

Below is a brief summary of the main findings and accomplishments associated with the first three sub-tasks. Work carried out under the last sub-task (Task B.4.) is described in a separate report prepared by the consulting firm Robert Bien and Frost (RBF).

Task B.1. Characterize sewage-contaminated shallow groundwater

In this task a set of studies were carried out collectively aimed at characterizing fecal pollution in the shallow groundwater beneath the City of Avalon, and the exchange of shallow groundwater with Avalon Bay. Major results obtained are summarized as follows (Figure 1 is a map showing the location of field studies described below):

1. Electrical resistivity surveys--including marine electrical resistivity (MER) surveys

FINAL REPORT

and electrical resistivity tomography (ERT) studies--revealed several areas of the Avalon Bay shoreline where brackish shallow groundwater is discharged to the Bay, including near the Pleasure Pier, at Busy Bee Wharf, and at Step Beach. Repeated ERT measurements at Pleasure Pier, Busy Bee, and Step Beach indicate that shallow groundwater discharge at these locations is modulated by the tides. Saline water from Avalon Bay flows into the shallow aquifer during rising tides, and brackish groundwater flows out of the shallow aquifer into Avalon Bay during ebbing tides. The resistivity surveys cannot determine the source of high resistivity (lower salinity) water in the shallow aquifer. Possible sources include meteoric water (i.e., from rainfall), infiltration of surface water, and sewage from leaking sewer lines.

2. A total of 27 shallow groundwater wells were installed in the City of Avalon. 20 of these wells were arranged in a "picket fence" along the Avalon Bay shoreline. The remaining 7 wells were installed at various inland locations, including landward of the Pleasure Pier along Catalina Avenue, and landward of Step Beach. All wells were screened between 1 and 2 m below ground surface, and surveyed to within sub-meter accuracy; well head elevations were also determined for a subset of wells. The location of the wells, relative to Avalon Bay and the sewer line infrastructure in the downtown area, is displayed in Figure 1.
3. The 27 shallow groundwater wells were sampled over a range of time scales (hours to months) and weather conditions (dry to wet). Shallow groundwater samples were assayed for salinity and the culture dependent fecal indicator bacteria (FIB) *Escherichia coli* (cEC) and enterococci bacteria (cENT). Most of the shallow groundwater samples had FIB concentrations at or below the detection limit (10 MPN/100 mL). FIB concentrations above the detection limit, and in some cases above the AB411 criteria for marine bathing waters, were measured in shallow groundwater near the Pleasure Pier, in front of Busy Bee, and at Step Beach. Salinity at these sites varied from oceanic (ca., 32) at the Pleasure Pier, to slightly fresher in front of Busy Bee (ca., 28), to brackish at Step Beach (ca., 15 to 20). The salinity of shallow groundwater also varied significantly in the cross-shore direction. For example, along Catalina Avenue the salinity of shallow groundwater increased from less than 10 to more than 30 over a horizontal distance of less than 30 m.
4. Shallow groundwater sampled from wells near Step Beach, and in front of the Busy Bee Wharf, had a number of additional characteristics consistent with sewage contamination, including: (1) elevated orthophosphate (upwards of 10 μ M); (2) low dissolved oxygen (<0.2 mg/L); (3) elevated ammonia concentration (upwards of 10 μ M); (3) a sulfidic smell; and (4) an unusual gray color.
5. Several advanced microbial source tracking (MST) methods were employed to determine the source of FIB in the shallow groundwater beneath the City of Avalon. 61 putative ENT isolates were cultured from inland wells. These isolates were identified to genus and species using an automated biochemical substrate utilization system. Of the 61 isolates analyzed, 46 belonged to the genus *Enterococcus*, and of the confirmed *Enterococcus* isolates 100% were identified as *E. faecium*. The fact that *E. faecium* was

FINAL REPORT

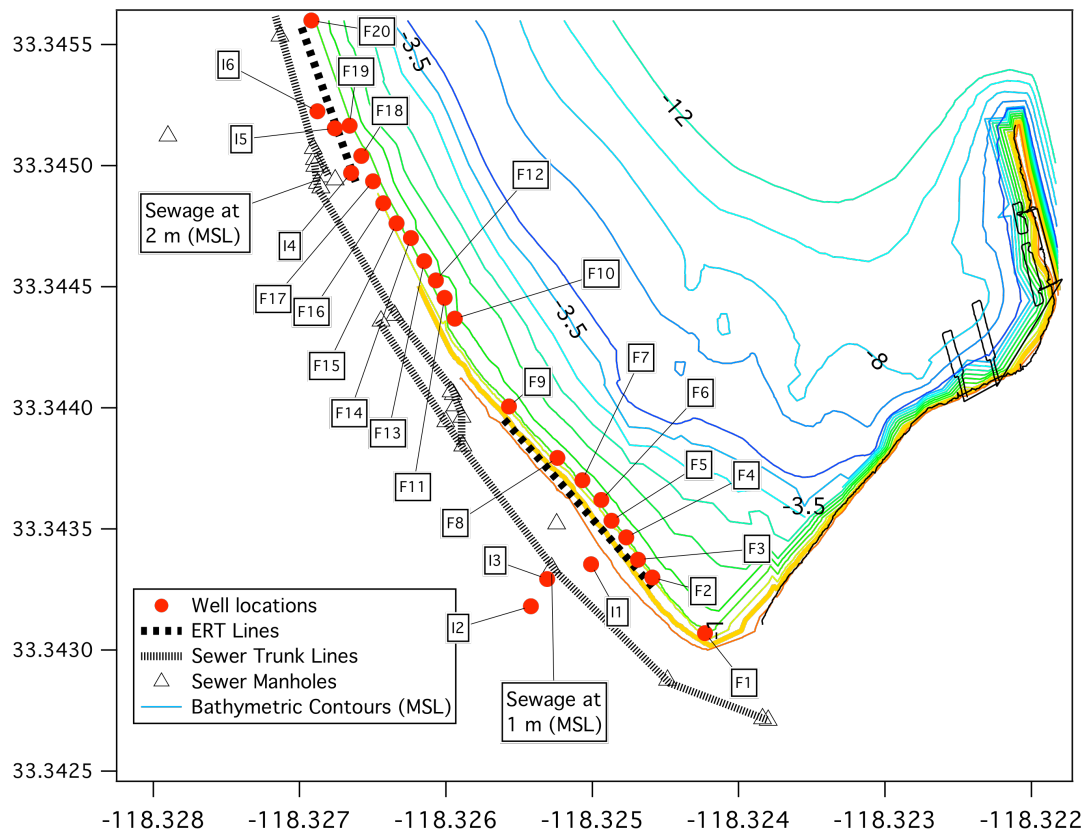


Figure 1. Map of Avalon Bay showing the location of studies carried out as part of Task B.1. Bathymetric contours of the Bay are in meters relative to mean sea level (MSL). Also shown are the elevation of the sewer trunk line at 2 locations along the waterfront

the only *Enterococcus* species isolated from the inland wells is consistent with the differential survival, or perhaps even environmental proliferation, of *E. faecium* in the shallow groundwater. Unfortunately, a relatively low number of isolates were cultured from foreshore wells, so it is not known if the low enterococci species diversity associated with inland wells also applies to shallow groundwater closer to the Bay, including wells located near Pleasure Pier, Busy Bee Wharf, and Step Beach where the shallow groundwater may be contaminated with sewage.

6. Samples collected from foreshore wells, inland wells, raw sewage, and the ocean were tested, using quantitative polymerase chain reaction (qPCR), for four groups of *Bacteroidales* spp., including universal, human-specific, dog-specific, and cow-specific; in addition, groundwater samples were tested for the bird-specific organism *Catellibacterium marimallium*. Furthermore, all samples were divided in two and tested with and without the addition of propidium monoazide (PMA), which inhibits the qPCR amplification of nucleic acid from cells with compromised cell membranes or present extracellularly. The universal *Bacteroidales* marker, which is generally associated with fecal waste of one

FINAL REPORT

form or another, was detected in all water samples collected from foreshore wells, inland wells, and the ocean. The human-specific *Bacteroidales* marker was detected in an inland well and in an ocean sample but not in foreshore wells. The dog-specific *Bacteroidales* marker, which can cross-react with both human stool samples and with sewage, was detected in all samples, but at particularly high concentrations in water collected from an inland well and the ocean. The cow-specific *Bacteroidales* marker was measured at high concentration in an inland well and in the ocean, but not in the foreshore wells. The bird-specific *Catellibacillus marimallium* was not detected in any shallow groundwater samples. PMA results yielded conflicting information (e.g., in some cases addition of PPM lowered the qPCR signal, while in other cases it increased the qPCR signal), and consequently further studies are needed to interpret the PMA results. Collectively, these results demonstrate that *Bacteroidales* is relatively ubiquitous in the shallow groundwater beneath the City of Avalon, and point to locations near specific inland wells where further testing may be warranted.

7. Water level was monitored continuously (every 15 min.) for approximately 1 month in six foreshore wells, and four inland wells. Water levels measured in all ten wells displayed tidal and fortnightly (spring-neap) variability, although the timing and magnitude of fluctuating water levels varied in both cross-shore and along-shore directions. As expected from other studies of tidally influenced flow in unconfined aquifers, tidal fluctuations in the shallow groundwater are progressively attenuated and time delayed with increasing distance landward of the beach. Water levels measured in closely spaced wells near Step Beach exhibit significant well-to-well variability in the timing and attenuation of tidal fluctuations, suggesting that subsurface flow in that region is complex and three-dimensional.

8. Overall, these results are consistent with the hypothesis that FIB contamination along the shoreline in Avalon Bay is caused, at least in part, by the discharge of sewage-contaminated shallow groundwater into the Bay. Based on the results presented in this chapter, future mitigation efforts should focus on three areas along the Avalon Bay shoreline—Pleasure Pier, Busy Bee Wharf, and Step Beach. A number of lines of evidence indicate that shallow groundwater at these sites may be contaminated with sewage, and geophysical measurements suggest that shallow groundwater in these areas undergo significant exchange with Avalon Bay.

Task B.2.—Pilot Disinfection Studies

Activities in this task were centered around pilot testing several different strategies—including chemical disinfection, permeable treatment barriers, and subsurface mobilization of fecal pollution using linear alkylbenzene sulfonates—for remediating fecally polluted shallow groundwater beneath the City of Avalon. These studies support the following conclusions:

1. A series of laboratory-scale studies were carried out to evaluate four disinfection strategies for removing sewage-associated FIB (in particular, culture-dependent measurements of enterococci bacteria (cENT) and *Escherichia coli* (cEC)) from shallow groundwater in Avalon Bay: (1) aeration alone, (2) aeration with

FINAL REPORT

- addition of brine, (3) aeration with addition of peracetic acid (PAA), and (4) aeration with addition of peroxymonosulfate (Oxone). The effectiveness of these different disinfection strategies was evaluated by reporting the log reduction in FIB concentration achieved after a 15 minute exposure time. A schematic of the laboratory set-up used in these experiments is shown in Figure 2.
2. Aeration alone and aeration with brine did not significantly reduce cEC and cENT concentrations in mixtures of raw sewage and shallow groundwater; i.e., no reduction in either cEC or cENT was achieved after 15 minutes of exposure.
 3. Four to 5 mg/L of PAA achieved > 3 log reduction of cEC and cENT in mixtures of raw sewage and shallow groundwater after 15 minutes of exposure. The biocidal properties of PAA do not appear to be affected by the salinity of the mixture.
 4. Disinfection of cEC and cENT by Oxone depends significantly on salinity; all else being equal, greater log-reduction was achieved at higher salinities.
 5. In general, cENT was more resistant to disinfection by both Oxone and PAA than cEC.
 6. The formation of hypohalous oxidants probably accounts for the enhanced biocidal properties of Oxone at high salinity, and implies that Oxone is likely to form toxic disinfection by products (DBPs) in marine waters.
 7. Based on these results, it does not appear that Oxone would be appropriate for any application in which the disinfectant, or its DBPs, might find their way into Avalon Bay.
 8. Particulate matter naturally present in shallow groundwater strongly interferes with PAA disinfection. Therefore, the turbidity of ambient waters must be factored into the design of a successful strategy for remediating sewage-contaminated shallow groundwater in Avalon.
 9. For above-ground pump and treat remediation to be effective, a procedure must be developed for effectively mobilizing FIB out of sewage contaminated sediments into the pore fluids, where they can be pumped to the surface and treated. We hypothesized, based on previously published studies involving the mobilization of viruses in sewage contaminated groundwater, that injection of linear alkylbenzene sulfonates (LAS) might mobilize FIB out of sewage-

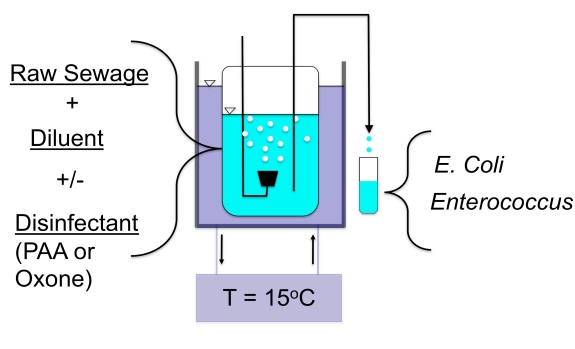


Figure 2. Schematic of the batch experiments used to evaluate the disinfection of sewage-contaminated shallow groundwater.

FINAL REPORT

contaminated sediments, but that does not appear to be the case based on packed column experiments carried out with both coarse and fine-grained sediments from Avalon's main beach area. Interestingly, we found that a significant fraction (50 to 99%) of FIB in sewage contaminated groundwater were removed by passage through just 28 cm of beach sand, suggesting that the native sediments have significant filtration capacity, even when the pore fluids possess brackish salinities (15).

10. Within the resolution of the filtration set-up used here, granular activated carbon (GAC) did not remove sewage-derived FIB to any appreciable degree. While better filter media could probably be found, permeable treatment barriers are probably not a viable option in any case, given the spatially complex and temporally variable nature by which sewage contaminated shallow groundwater is exchanged with Avalon Bay.

Based on the data obtained from these pilot studies, the most promising remediation approach would appear to involve the use of the chemical disinfectant PAA, either applied directly to sewage contaminated sediments, or injected into high-risk laterals, like those that pass through foreshore sands (e.g., connecting sewage lines at the Pleasure Pier to sewer mains in the downtown area of Avalon). Pump and treat methods and permeable treatment barriers are less promising, because of unresolved difficulties associated with mobilizing FIB and pathogens out of sewage contaminated sediments, and proper placement of in situ filter media in the face of a contamination plume that is highly variable in both space and time.

Task B.3.—Source Identification of FIB in Ankle Depth Waters in Avalon Bay

The field investigations described in this task were intended to identify sources of FIB in ankle deep water in Avalon Bay, and determine how these bacteria are mobilized into shoreline waters by either “overbeach” or “through beach” transport processes. Primary findings from this effort are summarized as follows:

1. FIB concentrations in surficial sand pore fluids are consistently elevated at two locations: (A) in front and upcoast of the Busy Bee Wharf, and (B) downcoast of the Pleasure Pier. It also appears that culturable enterococci bacteria (cENT) concentrations are frequently elevated in pore fluids with brackish salinity. FIB measured in waist deep Bay waters are frequently elevated near the Busy Bee Wharf, and more rarely near the Pleasure Pier.
2. Radon-222 activity measured along the Avalon Bay shoreline lends credence to the idea that shallow groundwater is discharged into the Bay on falling tides.
3. There is additional evidence that FIB may be associated with Bay water containing elevated radon activity and depressed salinity. During one of the shoreline surveys (on 11/12/08), two locations were identified as radon “hot spots” and likely areas of significant shallow groundwater discharge during low tides: southeast of the Pleasure Pier, and near the Busy Bee Wharf.

FINAL REPORT

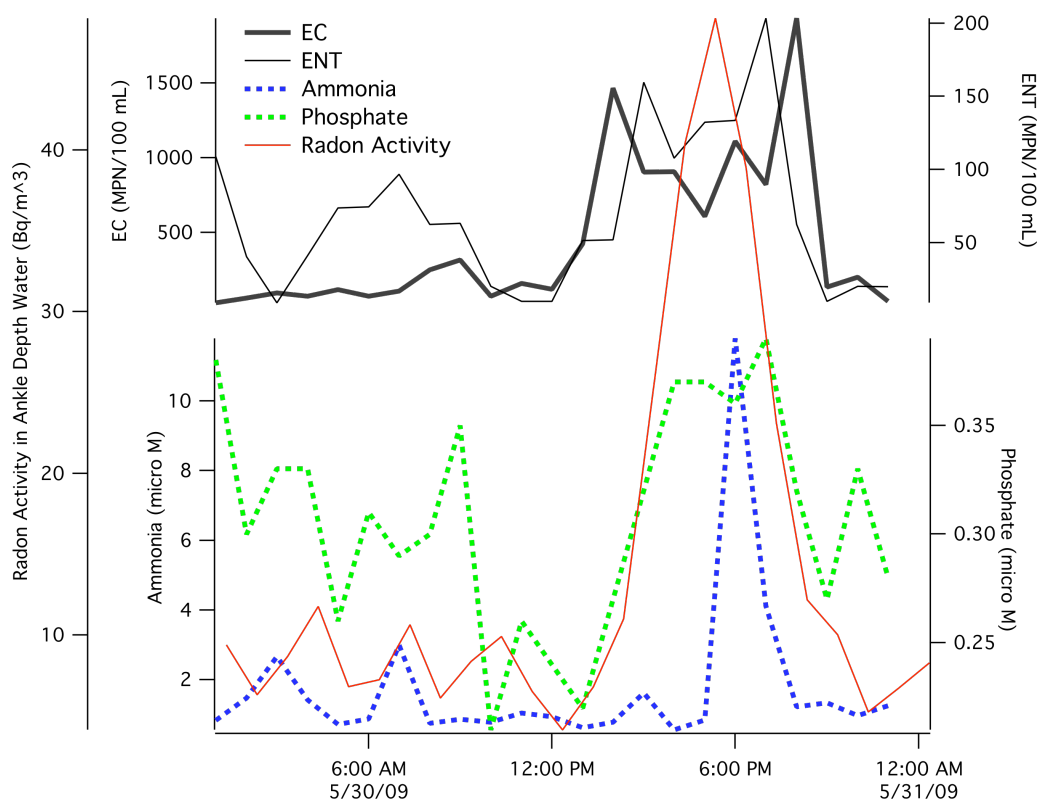


Figure 3. Comparison of Radon-222 activity, FIB concentrations, and nutrient concentrations measured in ankle deep waters at the Pleasure Pier.

4. Nearshore currents along the shoreline in Avalon Bay are dominated by boat traffic, including boats docked at the Pleasure Pier and large passenger ferries that run their reverse thrusters continuously while docked at the Mole. Nearshore currents generated from these docking activities typically manifest as westerly current pulses that last approximately 1.5 hours and have peak velocities of approximately 25 cm/s. The nearshore currents could affect FIB concentrations in ankle depth waters in several ways; e.g., by resuspending particle-associated bacteria off of the sediment bed, and by advecting clean (or polluted) water toward the main beach area. A research article describing the influence of boat currents in Avalon Bay on shoreline water quality was accepted for publication in the journal *Environmental Science and Technology*.¹
5. Conductivity-Temperature-Depth (CTD) profiles in the nearshore region of Avalon Bay revealed little in the way of temperature, salinity, or depth stratification, as evidenced by relatively low Buoyancy Frequencies (0.013/s). There is a subtle but consistent increase in Bay water salinity during large ebb tides, suggesting that at least a portion of the shallow groundwater discharged to the Bay is hypersaline (i.e., salinity in excess of oceanic salinity).
6. Water samples were collected along a groundwater-to-ocean transect, and analyzed for nitrogen species (nitrate, nitrite, ammonia) and orthophosphate. In

¹ Ho, L.C., Litton, R.M., Grant, S.B. (2011) "Anthropogenic currents and shoreline water quality in Avalon Bay, California", *Environmental Science and Technology*, in press.

FINAL REPORT

- addition, samples were analyzed for the relative distribution of the ^{16}O and ^{18}O of oxygen in water. The oxygen isotope studies indicate that, to a first approximation, shallow groundwater beneath Avalon is a variable mixture of meteoric groundwater and recirculated Bay water. Street runoff was isotopically similar to ocean water, probably reflecting the fact that the domestic water supply in the City of Avalon is generated by reverse osmosis desalination. Raw sewage had an isotopic signature intermediate between ocean water and meteoric groundwater, perhaps reflecting the infiltration of meteoric groundwater into the sewage collection system.
7. The different nitrogenous species measured (nitrate, nitrite, and ammonia) were summed to yield the total dissolved inorganic nitrogen (DIN), and compared to the dissolved inorganic phosphate (DIP) as orthophosphate. Sewage, groundwater, and Avalon Bay water can be distinguished by their DIN and DIP concentrations. The DIN and DIP concentrations measured in several shallow groundwater wells (including inland well IW3 located near the Marlin Club and foreshore well W19 near Step Beach) were consistent with significant levels of sewage contamination, ranging from 1 to 20% by volume.
 8. High frequency measurements of FIB, Radon-222 activity, and nutrients next to the Pleasure Pier support the hypothesis that foreshore sands and ankle depth water infuse with FIB-laden shallow groundwater as the hydraulic gradient tilts toward the Bay with the falling tide. Measurements of ammonia and orthophosphate in ankle deep water at the Pleasure Pier also increase with the falling tide (Figure 3).
 9. FIB concentrations along the shoreline of Avalon Bay appear to be correlated with several environmental variables, including temperature (negative correlation), onshore wind (positively correlated), and wave period (positively correlated). These associations may reflect the influence of environmental conditions on the sourcing, fate, and transport of FIB in Avalon Bay.
 10. Measurements of temperature profiles in foreshore sands reveal that, at specific times during the tidal cycle, pore fluids in the foreshore exhibit an inverse temperature gradient (i.e., colder water sits on top of warmer water) sufficient to cause the convective overturning of pore fluids. Convective turnover of foreshore pore fluids may “eject” FIB laden pore waters into the Bay.
 11. Overall, these data support the hypothesis that sewage-contaminated shallow groundwater is discharged to Avalon Bay at specific locations along the shoreline—specifically Pleasure Pier, Busy Bee, and Step Beach. Furthermore, evidence is presented that the seepage face—which forms when water level in the Bay drops below the shallow groundwater table—is contaminated with sewage markers.
 12. The possibility that foreshore sediments in Avalon are periodically infused with sewage-contaminated shallow groundwater raises the possibility that human-sand contact may represent a route for the transmission of fecal-oral disease at this site.